METHOD FOR INTERFEROMETRIC RADAR MEASUREMENT

Ins A1

The invention relates to a method for interferometric radar measurements as defined in the introductory part of claim 1.

Ins. B1

Owing to their construction, radar devices are precise range-finding systems, which means that without special measures, a radar device is capable of determining only the distance of a target from the antenna, but not its direction. It is possible to determine only whether or not a target is present within the lobe of the antenna.

Said problem is eliminated to a large extent in conjunction with the ROSAR or Heli-Radar system known until now by using, for example 16 vertically staggered antennas with an antenna opening angle of, for example 2.5°. It is possible with such an system to determine the location of an elevated obstruction etc. within an accuracy of about 2.5° in terms of elevation. However, targets located at the same distance are also in this case displayed in the same antenna in the same image spot.

The azimuthal resolution of the known Heli-Radar system amounts to about 0.2° because of a special signal processing. Reference is made in this connection to the disclosure in DE 39 22 086 C1. However, the direction of an obstruction and thus the location in space at which such obstruction is located can be determined only with the help

of a triangulation, whereby two locally separated radar installations can be employed for said purpose in the simplest case.

However, it is possible also to make use of the properties of a coherent radar system and to carry out a type of triangulation with the help of the phase of the emitted signal. For this purpose, a coherent radar system is employed which coherently transmits a signal via a transmitting antenna and receives the echoes scattered back via two locally separated receiving antennas. A coherent evaluation permits a calculation of the phase difference between receiving signals. The direction from which the scattered echoes are received is determined based on the phase difference. Now, once the distance and direction of an "obstruction" have been computed, its location in space can be determined as well. Said type of three-dimensional determination of a location with the help of a coherent radar system comprised of one transmitting antenna and two receiving antennas is generally referred to as "radar interferometry" and known since a long time. It is employed already for the generation of topographic charts with the help of SAR-systems installed on aircraft, for example by the DOSAR system of the firm Dornier GmbH.

Reference is made in this connection to the following published documents pertaining to the further state of the art:

(a) C.T. Allan, Review Article, Interferometric Synthetic Aperture Radar, in IEEE Geoscience and Remote Sensing Society News Letter, September 1995, p. 6 ff;

(b) S. Buckreuss, J. Moreira, H. Rinkel and G. Waller, Advanced SAR Interferometry Study, DLR Bulletin 94, June 10, 1994, Institut für Hochfrequenztechnik, Oberpfaffenhofen.

The entire prior art known to this date and the state of the art cited above, including the ROSAR principle on which the present invention is based, projects terrain elevations or other elevated obstructions in one plane, so that it is not possible to recognize the elevation of the given obstruction if the reproduced topography of the terrain present is unknown. However, a three-dimensional image is required for controlling flights.

The present invention is based on the problem of proposing on the basis of the ROSAR principle measures that permit a quasi-three-dimensional image representation of terrain and other obstructions.

Sub B2

B2 Said problem is solved with the help of the measures proposed in claim 1 in a surprisingly simple manner. Variations and further developments of the invention are specified in the dependent claims, and an exemplified embodiment of the invention, which is sketched in FIG. 1, is explained in the description. In the drawing,

Sub B3

FIG. 1 shows a schematic representation of an exemplified embodiment with respect to the typical geometry for an interferometric ROSAR system,

FIG. 2 shows a block diagram of the exemplified embodiment according to FIG. 1,

FIG. 3 is a perspective view of the state of the art with respect to the ROSAR principle.

Sub B4

According to the general idea of the invention, the goal is to obtain in conjunction with a helicopter operating according to the ROSAR-system a quasi-three-dimensional radar image representation for flight guidance by associating with a transmitter located on the rotating rotary cross two coherent receiving antennas with receiving channels.

The ROSAR-system employed heretofore is comprised of, for example 16 transmitters and receivers with their channels

for obtaining a three-dimensional image. However, said transmitters and receivers have a directional inaccuracy of about 2.5°. Now, if said ROSAR-system, as mentioned above, is expanded by a highly precise coherent receiving channel, only one transmitter and two coherent receivers instead of the, for example sixteen transmitters and receivers employed until now will be required for obtaining the highly precise three-dimensional radar image. The directional inaccuracy found until now is enhanced by the interferometric principle by about the factor 100.

This is explained in the following description of an exemplified embodiment of the invention, which is sketched in FIG. 1.

A helicopter operating according to the ROSAR principle flies over the surface of the earth at an altitude H. One transmitting antenna and two receiving antennas with associated coherent transmitting and receiving electronics are mounted on the end of the rotating antenna cross. The received echoes are amplified, digitized and processed further.

INS C1

The distance between said arrangement as described above, which is referred to in the following as the INROSAR-system, and the impact point P, which is located at a relative altitude h, is referred to as R. The distance from the

antenna A1 of the INROSAR-system to the impact point P amounts to R + ΔR and is therefore by a small amount ΔR greater than the distance R to the antenna A2. The difference ΔR between the two distances can be calculated based on the known wavelength λ of the emitted radar signal and the measured phase difference $\Delta\phi$ of the receiving echo of the two coherent receiving channels.

Now, said phase difference $\Delta\phi$ of the receiving echo is in turn calculated based on the images generated by processing the receiving echo. Each of the two images is present in a complex, digital form, i.e. it comprises a real part and an imaginary part, or equivalent: the amplitude and the phase.

Now, the phase difference $\Delta\phi$ follows up to a multiple of π (modulo π) through complex multiplication of the image points of the one image with the conjugated complex image points of the other image, and subsequent formation of the arctangent of the respective real and imaginary parts. The phase difference $\Delta\phi$ is obtained in this way, and by inserting $\Delta\phi$ in equation 1, ΔR is then obtained.

$$\Delta R = \frac{\lambda}{4\pi} \Delta \Phi \tag{1}$$

The phase centers of the two receiving antennas A1 and A2 are removed by the length B, the so-called base line. The following results from the cosinus theorem and a few simple angle relations:

$$\cos(\theta) = \frac{(R + \Delta R)^2 - R^2 - B^2}{2 \cdot R \cdot B} \tag{2}$$

After the sight angle θ has been calculated in equation (2), it is now possible to determine the relative altitude h as follows:

$$h = H - R \cdot \cos(\theta) \tag{3}$$

Ins. B6

B5 ~~The altitude h is actually not required in connection~~ with the INROSAR system for representing the image dots on the graphics display screen, but only ~~the~~ sight angle θ is used for calculating the coordinates ~~of~~ B6 an impact point P on the graphics display screen. Furthermore, whether the angle of inclination of the antenna is known or not is unimportant as well because the representation on the display screen is only a ~~relative representation~~ of the image dots ~~with~~

respect to the vertical line in relation to the base line B of the two antennas A1 and A2. The representation of the image is in fact dependent upon the position of the helicopter, for example due to the pitching; however, the antennas of the INROSAR-system and the center of the image are always in a fixed relation to each other. The altitude h and the angle of inclination α of the antennas are only required if a topographical chart with an absolute altitude H of the area over which the aircraft is passing is to be generated with the help of said INROSAR-system. The formulas specified above are useful also for a consideration of errors, as will be explained in the following.

The errors relevant to the INROSAR-system are the phase noise $\delta\phi$ and the change in the base line B between the phase centers of the antennas A1 and A2. The phase noise is composed of the sum of proportions of the different components. The greatest contributions are supplied by the transmitter, the receivers, the system timer and the noise of the A/D-converter. A typical order of magnitude for the entire phase noise $\delta\phi$ of an INROSAR-system amounts to approximately 5°. The change in the base line between the phase centers of the antennas A1 and A2 may be caused, for example by heating due to the incidence of sunlight rays. 0.001 m is assumed to be a typical value. The various

influences result in a scatter δh of the altitude of the impact point P and thus in a scatter of the sight angle $\delta\theta$.

$$\delta h = \frac{\lambda \cdot R}{4\pi \cdot B}\,\delta\phi \tag{4}$$

$$\delta h = -R \cdot \tan(\theta)\frac{\delta B}{B} \tag{5}$$

This results in scatter of the sight angle $\delta\theta$ as follows:

$$\delta\theta = \arcsin\left(\frac{\delta h}{R}\right) \tag{6}$$

INS C2

In conjunction with an exemplified embodiment according to FIG. 1, the helicopter flies in the normal position, which means that the antennas A1 and A2 are positioned vertically one on top of the other. ΔR is determined based on equation (1). The value of the measured phase difference $\Delta\phi$ of the echo from the antennas A1 and A2 is ambiguous and can be determined only down to a value ranging between 0 and

2π. Said ambiguity of ~~2π~~ has to be determined by means of additional measurements. Suitable for said purpose is a transmitter/receiver complementing the INROSAR conception that ~~is~~ comprises a transmitting/receiving antenna that is sharply focussed in elevation and covers the lower range of the sight angle. The distance to the impact point on the ground can be clearly determined based on the receive echo because of the sharp focussing in elevation of said transmitting/receiving antenna. The INROSAR-system accepts said distance as a basic value and calculates the further ambiguities based on the rising distance from the continuous phase transitions. The following calculation example supplies the detailed explanations.

The calculation is based on the situation that the helicopter flies in its normal position. This means that the antennas A1 and A2 are vertically arranged one on top of the other.

The following parameters apply:

Parameter	Meaning	Value 1/Value 2
H	flight altitude of INROSAR	100 m
$R + \Delta R$	Distance between impact point P and antenna A1	Example 1: 500.009 m Example 2: 500.09 m
R	Distance between impact point P and antenna A2	500.00 m
B	Base line between the phase centers of the antennas	0.15 m
δB	Error of length of base line B	0.001 m
$\delta\phi$	Phase noise of the INROSAR system	5°
α	Angle in inclination of antennas A1 and A2	90° (vertically)
λ	Radar wavelength	0.0090909

From equation (2) follows:

$$\theta = \arccos\left(\frac{(R + \Delta R)^2 - R^2 - B^2}{2 \cdot R \cdot B}\right) \qquad (7)$$

Example 1

$$\theta 1 = \arccos\left(\frac{(500.009^2 - 500.000^2 - 0.15^2)}{2 \cdot 500.000 \cdot 0.15}\right)$$

$$= \arccos(0.05985)$$

$$= 86.57°$$

$$h1 = 300 - 500.00 \cdot \cos(86.57°)$$

$$= 70.09 \text{ m}$$

Example 2

$$\theta 1 = \arccos\left(\frac{(500.09^2 - 500.00^2 - 0.15^2)}{2 \cdot 500.000 \cdot 0.15}\right)$$

$$= \arccos(0.0599904)$$

$$= 53.14°$$

$$h1 = 300 - 500.00 \cdot \cos(53.14°)$$

$$= 0.048 \text{ m}$$

From the equations (4) and (5) follows for the scatter δh of the altitude h of the impact point P:

$$\delta h_{\delta\phi} = \frac{0.00909 \cdot 500.00}{4 \cdot \pi \cdot 0.15}(5°/57.3°)$$

$$= 0.21 \text{ m} \qquad - \quad \text{exactly: } 0.210401168 \text{ m}$$

$$\delta h_{\delta B} = -500.00 \cdot \tan(53.14°) \cdot \frac{0.001}{0.15}$$

$$= 4.45 \text{ m} \qquad \text{based on (2): } 2.035 - 0.048 \text{ m}$$

This results in a scatter of the sight angle $\delta\theta$ as follows:

Due to phase noise, $\delta\phi = 5°$:

$$\delta\theta = \arcsin\left(\frac{0.21}{500.00}\right)$$

$$= 0.02°;$$

and because of errors in the length of base line B by δB = 0.001 m:

$$\delta\Phi = \arcsin \frac{4.45}{500.00}$$

$$= 0.5°.$$

FIG. 2 shows a block diagram of the exemplified embodiment shown in FIG. 1. Said block diagram is equipped with the components required for the proposed interferometric radar method and requires no further explanations for the expert in the field.